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SPECIAL LASER SYSTEM AUTOMATICALLY OPTIMIZED PROGRAM PROCESSING

by

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I. INTRODUCTION

In infrared and laser technology applications, use is often made of a number of special optical systems--in their overall layouts, they lose coaxial symmetry characteristics. In terms of system components, one has the appearance of special optical aspects--for example, in laser working technology, it is necessary to use circular cone surfaces to extract good quality ring belt laser beams. In laser scanning systems, it is necessary to use torroidal surface components to carry out rotary scanning. In semiconductor laser systems, it is possible to opt for the use of cylindrical surface lenses and shape corrective components to improve light beam collimation characteristics. In night vision instruments, it is possible to use numerical value apertures associated with Fresnel lens enlargement systems, and so on along these lines. As far as these types of optical systems are concerned, due to their special structures themselves, relying on manual labor makes is extremely difficult to design good results. It is only with the application of computers to the execution of structural parameter automation that one has the best way to resolve problems. However, because this type of system is very different from traditional coaxial spherical systems, a number of new problems will undoubtedly appear with the automatic optimization. This article attempts to put forward methods for solving a number of difficult points in them.

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II. STRUCTURAL PARAMETER INDEPENDENT VARIABLES AND "COMPARATIVE PROCESSES"

As far as the various types of special optical systems discussed above are concerned, they often include special structural parameters which do not appear in traditional coaxial spherical systems--for example, torroidal rotating radii, vertex angles of circular conical surfaces, and so on, and so on. When appropriate independent variables for these special structural parameters are optimized with the whole system, how are the basic step length increments in question precisely determined? This is the most important question which must be resolved before automatic optimization begins. If these increment values are chosen too small, it is possible to make rounding errors between corresponding mass function finite differences and computers quite considerable, causing "finite difference" calculations to be completely without significance. If this type of increment value is chosen too large, it will also make "finite differences" exceed postulated permissible ranges. It is not possible to effectively substitute partial differentials, creating follow on calculation inconsistencies.

Mathematically speaking, at the present time, broadly popular automatic optimization methods (no matter whether they are damping least square methods or adaptive methods) all will be based on linear equation sets to solve for mass function variables:

(1) $$A \cdot \Delta X = \Delta F$$

In the equation

Δ X -- structural parameter variable vector array;

A -- finite difference element coefficient matrix for mass function F (also called difference matrix);

Δ F -- vector array using projected mass function variables as elements.

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Theory and practice both clearly show that the difference in the moduli of the various rows of matrix A will produce decisive influences on practical optimization processes. The reason is that vector arrays with irregular length parameter differences have a number of clearly restricting effects on the conditions of matrices (AT,A) and (AAT). For example, as far as the ratio between the maximum lengths and minimum lengths assembled in vector arrays are concerned, a number have important influences on the conditions of matrices ATA and AAT. Without doubt, in the case of the speed of development of automated optimization and final optimization results, there is a close relationship with overcoming the level of bad matrix conditions discussed above. Obviously, in order to make optimization processes achieve fast and stable convergence, one important prerequisite factor is to make mass function finite differences corresponding to various structural parameter independent variables roughly appropriate. This

then requires that, when we precisely determine increments associated with various structural parameter independent variables, real investigation should be done on the size of values selected.

In another area, speaking in terms of optical design personnel, there is also no doubt that they hope various structural parameters adequately exert their own calibrating effects in order to facilitate tapping as much as possible system optimization potential and taking the design of the whole system to an optimum state. This also requires that we carefully select the basic increments associated with various structural parameter independent variables.

As far as the case above is concerned, requirements for coaxial spherical system automated optimization are similar. However, due to the fact that a number of new special structural parameters appeared in the special optical systems discussed in this article, this problem then seems to be more striking. Even less is it the case when most of the mass functions [1] used in these special system automated optimization processes are based on vertical axis aberration curve areas associated with Qiebixuefu (phonetic) numerical value integral (called simply Qieshi indices). They are very different from traditional aberration functions. This just makes the problem even more complicated and more important. Because not only structural parameters are new, but even mass functions have also not appeared in the past--with regard to relationships of corresponding changes between them--people completely lack experience. This is a technology difficulty associated with realizing automated optimization in this type of special system.

In view of the situations discussed above, we designed a specialized process--automatically determining basic step

length increments associated with various new types of independent variable by computer. On the basis of calculations and comparisons of mass function finite differences, they make the mass function finite differences produced by various new types of structural parameter independent variable increments roughly appropriate. Because people already have replicable experience in choosing curvature increment values, as a result, this type of relatively useful curvature increment acts as standard. The actual method is:

(1) A test selection is made of a new structural parameter increment δx_j. Calculations are done of its corresponding mass function difference δf_j;

(2) Comparisons are made between δf_j and the mass function difference δf_c corresponding to curvature increments.

If

(2) $$|\delta f_j| > 5|\delta f_c|$$

then, take the new parameter increments in question and reduce them to be:

(3). $$\delta x'_j = 0.707\delta x_j$$

If

(4) $$|\delta f_j| < 0.2|\delta f_c|$$

then, select

(5). $$|\delta x'_j| 1.414\delta x_j$$

When

(6) $$0.2|\delta f_c| \leqslant |\delta f_j| \leqslant 5|\delta f_c|$$

only then does one believe that independent variable increments corresponding to $|\delta f_j|$ are basically reasonable. (Above, j=1,2,...n are serial numbers for new types of independent variables. The same below.)

(3) From an array of mass function differences satisfying equation (6), choose:

(7) $$\delta f_M = \max\{|\delta f_j|\}$$

(8) $$\delta f_M = \min\{|\delta f_j|\}$$

(4) If

(9) $$\delta f_M > 9\delta f_m$$

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it is still necessary to take independent variable increments corresponding to δf_M and reduce them. At the same time, /11 take independent variable increments corresponding to δf_m and enlarge them. The ratio between the reductions and the increases are respectively 0.707 and 1.414.

The process above, arranged from before the beginning of automated optimization and completed automatically by program is called simply "comparative process". As automated optimization, it precisely determines basic, reasonable structural parameter increments and arrives at independent variable change scales which are fundamentally unified. This is unusually important to the efficacy of balanced and adequate shifting of various types of structural parameter optimizations, improving solution conditions for iterative substitution processes, reducing divergence and slowing convergence.

It is worth pointing out that we say the independent variable increments determined by the "comparative process" described above are basically reasonable. However, this certainly does not mean that, during follow on optimization, we always immutably cite this type of increment. When optimization processes show the appearance of "pathologies" [2] or, for a special purpose, there is a need to make use of reweightings of independent variables of various types, it will still make adjustments to these increments. Of course, this type of adjustment lies again in changing the ratio relationships between them in order to make optimization directions generate changes.

III. LINEAR CHECKS AND STEP LENGTH CONTROL

Here, we still carry out "composite optimization" theory [3]. However, in the area of linear checks, in programs, strict standards are put into effect. This is based on the maximum factors obtained on the basis of the adjacent two iterations of iterative solutions (Xmax,X*max)

factors are:

$$K_x = \left(|X_{max}| - |X^{\cdot}_{max}| \right) \quad / p \tag{10}$$

On the basis of actual Kx values, programs precisely determine the substitution step length p* for the next iteration or reestablishes the coefficient matrix. Concrete criteria are as shown in Table 1.

Table 1 Criteria for Kx and p* or Reestablishment of Coefficient Matrices

Key: (1) Intervals Where Kx Exists (2) Reestablish Matrix

K_x 所在区间 (1)	(0.95 ,1.05)	(0.9,0.95] [1.05,1.1)	(0.85,0.9) [1.1,1.18)	(0.8,0.85] [1.18,1.25)	(0.75,0.8] [1.25,1.33)	(0.7,0.75] [1.33,1.43)	(−∞,0.7] [1.43,∞)
p^*	$2p$	$\sqrt{2}p$	p	$p\sqrt{2}$	$p/2$	$p/2\sqrt{2}$	重建矩阵 (2)

In normal situations, the first iteration step length is p = 1. When one has the appearance of "pathologies", the first iteration step length is p = 0.5. If there are still "pathologies", then the step length is reduced by half. When step lengths are reduced as far as 0.125, and "pathologies" have still not been gotten rid of, then adjustments are carried out to independent variable increment ratios. With regard to the details in this area, please consult reference [2], Chapter II, Section VI.

In comparison to coaxial spherical system automated optimization programs [4], the linear check standards put into practice here seem even more severe. The purpose is to reduce as much as possible nonlinear influences, making iterative optimization even more effective.

From Table 1, it is also possible to see that the amplitudes of adjustment step lengths for which option is made are also smaller than the adjustment amplitudes set out consulting reference [4]. As a result, step lengths increase case by case, but the differences between step lengths in two adjacent cases become smaller. The idea is to make step lengths turn somewhat more gentle and to take steps toward more cautious substitution.

IV. CHECKS AND PROCESSING ASSOCIATED WITH BOUNDARY QUALITY

We take data reflecting special optical system boundary quality and divide it into three types: (1) optical characteristics parameters; (2) exterior perimeter parameters; and, (3) material characteristics parameters.

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For example, such important parameters as system vertical axis expansion rates β optical focal powers within two orthogonal planes of intersection $\varphi_{T'}$ and $\varphi_{S'}$, relative distance out of pupil $l'_z\varphi_{T'}$, relative operating distance $l'\varphi_T$ and so on, belong to the first type. They display the optical properties of systems as they really are. What should be recognized is that important boundary conditions must be strictly controled. To this end, when designing programs, we take them and bring them into arrays of optimized indices. Programs are guaranteed through optimization processes based on user designated targets and tolerances. To say it another way, they originally also belonged to boundary conditions. However, in view of their striking importance, we do not treat them as boundary conditions, but treat them as mass function processing--direct optimization and strict control.

The second type, by contrast, includes minimum space intervals associated with adjacent surfaces in systems, special structural parameters (for example, circular cone surface conical vertex angles), and so on, and so on. With regard to the former, we first choose points on physical spacial axes and 0.884 visual field points. Individual records are made of the geometrical length of travel between adjacent surfaces for 14 Qiebixuefu (phonetic) sampling light rays. From among these, minimum δ

values are searched out. Comparisons are done between δ and minimum permissible interval values Dm stipulated by designers. If

$$\delta < D_m \tag{11}$$

then, it is believed that the interval in question violates boundary conditions. Programs automatically take corresponding central distances d and pull them out to be:

$$d^* = d + \sqrt{2}(D_m - \delta) \tag{12}$$

Because the processing described above not only considers physical points on axes but also considers physical points outside axes approaching the boundaries of fields of vision (In accordance with Qiebixuefu [phonetic] sampling methods, the maximum field of vision sampling coefficient is 0.884), from light beam structures, 28 spacial light beams possess good representative natures--Qiebixuefu (phonetic) interpolation theory guarantees this point. Therefore, we believe that this type of processing is appropriate. Program design is also not a problem.

With regard to circular conical surface hemiconical vertex angles θ, this is the most important structural parameter in circular conical surface systems. Under the definition we picked, if optimization processes show the appearance of:

(13) $$|\theta^{\cdot}| \geq 90^{\circ}$$

they are also recognized to be in violation of boundary conditions. As a result, programs opt for hemiconical vertex angles as:

(14) $$|\theta^{\cdot}| = 90^{\circ} - 0.25(|\theta| - 90^{\circ})$$

In conjunction with this, temporarily take this independent variable and "freeze" it (not acting as a variable).

As far as all "frozen" variables are concerned, from the time when they are "frozen", they are not seen as independent variables in the two follow on intermediate cycles.

As far as opportunities to check this type of boundary quality are concerned, we put them at the finish of each intermediate cycle. With the completion of each intermediate cycle (whether or not it completely reaches optimization objectives), programs must all carry out boundary checks across the board, and, in conjunction with this, handle one by one cases associated with the restraining of boundary condition violations.

The third type is limitations on optical materials used in systems. Generally, they are stipulated on the basis of the characteristics parameters of materials on hand (for instance, requirements to opt for the use of domestic materials, materials with good theoretical characteristics, or commonly used materials with low costs, and so on, and so on). With regard to this type of boundary restriction and investigating and taking care of violation phenomena, there are certainly no differences in principle between special optical systems and coaxial spherical

systems. This will not be repeated again here.

Limited by the scope of this article, with regard to other technology problems in special optical system automated optimization program design (for instance, image surface location, consistency of mass function definitions, sampling ray coordinate standards, and so on), we will discuss them elsewhere.

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